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DOI: https://doi.org/10.1523/JNEUROSCI.6133-11.2012

Originally published at:
Oud, Bastiaan; Coppin, Géraldine (2012). Extending the study of decision values to cases where options are presented using different sensory modalities. Journal of Neuroscience, 32(7):2248-2249.
DOI: https://doi.org/10.1523/JNEUROSCI.6133-11.2012

Journal Club

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Extending the Study of Decision Values to Cases Where Options Are Presented Using Different Sensory Modalities

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Review of Levy and Glimcher

Shall I go see a movie tonight, or rather buy some Chinese food? Obviously, such choices between different classes of goods ("reward types") are conceptually complex and methodologically challenging to investigate. Yet, they occur frequently in everyday life. How, then, does the brain solve such problems? The view that diverse behavioral acts and sensory stimuli may be compared via a value signal that is computed on a common scale, much like an internal currency (Montague and Berns, 2002), is gaining traction in decision neuroscience and neuroeconomics. According to this notion, a decision value is computed for each option. These are then compared, and the option with the highest decision value is most likely chosen. Such comparisons require that decision values are on the same scale—which is what the notion of a common currency captures.

The idea that choices can be described as the outcome of maximizing decision value (usually called decision utility in economics) is not new: it is at the very core of how economic theory describes consumer behavior. However, economic theory has been purposefully agnostic about whether there is actually a neural correlate of decision value, or whether this is merely a mathematically convenient description that predicts behavior well. When the groundwork for this approach was laid in the first half of the 20th century, this agnosticism was motivated chiefly by the assertion that valuation in the brain was practically inaccessible to direct measurement. The development of "revealed preference theory" (Samuelson, 1938) hence inverted the deductive chain and held that preferences (which imply decision values) can be inferred from choice, as long as choices are sufficiently consistent. More recently, however, due to advances in brain imaging technology, the question of whether this is actually how choices are implemented in the brain has become directly testable.

A growing body of neuroscientific research addresses this question. Previous studies in this vein have typically proceeded in two phases. In a first phase, decision values for choice options were estimated behaviorally, for a variety of reward types (e.g., food, non-food trinkets, monetary rewards). In a second phase, participants were exposed to the same choice options in an fMRI (functional magnetic resonance imaging) scanner. For each reward type, the researchers then identified regions in which neural activity correlated with the behaviorally estimated decision values. Regions in which activity correlates with all reward types are deemed candidates for common currency calculation.

Levy and Glimcher (2011) proceeded in a similar fashion. Participants were exposed to choice situations in which they were asked to choose between options from three different reward types: water, food, and money. In some trials, both options were from the same reward type (e.g., a certain small amount of water vs a larger but stochastic amount of water). These "same-type" trials permitted the authors to estimate decision values for each reward type and participant, as in previous work. However, crucially, there were also "mixed" trials where the two options that could be chosen were from different reward types. From these mixed trials, the authors estimated "scaling factors," which are a sort of behavioral exchange rate that makes it possible to convert decision values for all three reward types to a common scale. While previous work has shown that decision values for several different reward types are encoded in spatially overlapping brain regions (Chib et al., 2009), this by itself did not permit the conclusion that they are also encoded on the same scale, which is essential to the concept of common cur-

Received Dec. 4, 2011; revised Jan. 5, 2012; accepted Jan. 7, 2012.

B.O. gratefully acknowledges financial support from the Swiss National Science Foundation (Grant number PDFMP1-123113/1) and Ernst Fehr. G.C. gratefully acknowledges financial support from the National Center of Competence in Research for the Affective Sciences, the Swiss National Science Foundation (51NF40-104897), the University of Geneva, and a research grant from Firmenich, SA, to David Sander and Patrik Vuilleumier. The authors would like to thank Todd Hare and Tony Williams for insightful comments.

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DOI:10.1523/JNEUROSCI.6133-11.2012

rency. This gap is filled by the work of Levy and Glimcher (2011).

In a later session, participants were presented with a series of same-reward-type trials in an fMRI scanner. The authors then identified brain regions whose blood oxygenation level-dependent (BOLD) signal correlated with the common-scale decision values of the options presented. These decision values were estimated from the choices in the behavioral sessions, and converted to a common scale using the estimated scaling factors from the mixed trials.

The fMRI analysis revealed regions that encoded decision values selectively for one of the two reward types (posterior cingulate cortex for money and hypothalamic areas for food), as well as a subregion of ventromedial prefrontal cortex (vmPFC) that correlated with common-scale decision values for both reward types. The authors interpret this as evidence that value signals are likely first computed in several distinct reward-type-specific regions, and then converge in the vmPFC, in which decision values are encoded on the same scale, enabling direct comparison.

The identification of vmPFC as a common currency decision value area is in line with what has been proposed in previous work (Chib et al., 2009). It is further corroborated by a large body of research that, while not targeting common currency per se, has investigated decision values for a variety of other reward types (for an overview, refer to Fehr and Rangel, 2011). Examples range from simple choices among foods or trinkets, to more complex choices, e.g., between monetary gambles, delayed monetary rewards, or donations to charity. Together, there is thus considerable evidence that vmPFC correlates with decision values for many different reward types.

However, testing these correlations separately, one reward type at a time, is not sufficient to establish the notion of a common currency. As Levy and Glimcher (2011) point out, this demonstrates a spatial overlap, but it does not follow that the neural decision value signal for different reward types is also on the same scale. The method of using mixed-type trials to estimate exchange rates (scaling factors) across different reward types allows the authors to test this common scale property. The results support a fundamental tenet of the common currency hypothesis, since it is precisely the common scale property that would enable the comparison of decision values across reward types.

We note that the research reviewed here, as well as (to our knowledge) all previous work undertaken on common currency for decision values, presents stimuli visually at the time of decision. However, outside the laboratory, choices in which the options are experienced via different sensory modalities occur frequently. For instance, at a restaurant, you may hear a waiter describe some of the dishes available, yet prefer to order what you smell from the table behind instead. A truly universal common currency area thus ought also to encode decision values for options presented across different sensory modalities.

Surprisingly, this appears not yet to have been directly tested. Perhaps this is due to the comparative ease of presenting stimuli visually in the scanner. However, with the increasing spread of MRI-compatible olfactometers, gustatometers, and tactile stimulators, the required technology is now more readily accessible than ever.

Levy and Glimcher's (2011) approach of harnessing mixed-choice situations to establish common-scale encoding seems well suited for adaption to cases where options are presented using gustatory, olfactory, or, perhaps most easily, auditory modalities. For instance, participants might hear short acoustic samples of songs, before making their choice of which song(s) they would like to receive as a full copy. In analogy to Levy and Glimcher's (2011) method, one would combine such "same-modality" trials with "mixed-modality" trials, in which participants decide between options presented via different modalities, e.g., where they decide between music presented via the short auditory previews and music that is presented visually (using album covers).

Varying modalities can in principle be combined with varying reward types. From an experimental point of view, one would want to vary these two dimensions as independently as possible. This restricts what kinds of options can be offered in such an experiment, since some rewards are not easy to identify across different sensory modalities. For instance, it is hard to identify money by smell. Hence, to extend Levy and Glimcher's (2011) design (using same- and mixed-reward type trials) by this additional dimension (same- and mixed-modality trials), one would have to present participants with options that can be identified easily across the modalities used in the study.

It should be noted that although several studies (Plassmann et al., 2008; Valentin and O'Doherty, 2009) have delivered stimuli using modalities other than vision in the scanner, these studies were designed to answer different questions and hence do not resolve the issue we raise here. First, all stimuli within each of these studies were presented in the same way, i.e., there were no mixed-modality choices of the sort we are proposing. Second, non-visual stimulus presentation occurred not at the stage of decision value, but at later stages, designed to track outcome value (upon consumption) or anticipated value (after decisions but before consumption).

To conclude, Levy and Glimcher's (2011) study convincingly makes the case that vmPFC encodes decision values for food and monetary rewards on a common scale. We believe their experimental design is well suited for an extension to choice situations where the options are presented using different modalities.

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